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We would like your views and opinions on the content of Beaufort magazine. Simply drop us a line care of The Editor, Beaufort Magazine, Dome Petroleum Limited,.....

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Cover Photograph: The trans Alaska pipeline of the Alyeska Pipeline Service Company is our cover for this edition of **Beaufort** Magazine. The Alyeska line has proven to be one of the most successful oil pipelines ever built, and transports 1.6 million barrels of oil a day over 1260 kilometres of rugged Arctic and mountainous terrain. The line, in operation since 1977, has had minimal impact upon the ecosystem and animal life of Alaska and is an excellent application of pipeline technology to serve national energy needs. (Photo courtesy Alyeska Pipeline Service Company).

Beaufort is published by Dome Petroleum Limited, Esso Resources Canada Limited and Gulf Canada Resources Inc. to provide the general public, and interested parties, background information on the long range development and production of hydrocarbons from the Beaufort Sea and Mackenzie Delta. In terms of engineering and technical skills production is attainable in this region by the mid-80s. Before approval in principle is obtained from the federal government, a detailed report on the possible effects and impacts of such production must be prepared. This report, known as the Environmental Impact Statement, is to be completed in the summer of 1982. The E.I.S. will address the issues and concerns raised by the production scenario. BEAUFORT will report on the progress of the E.I.S. and the energy industry's evolving plans to address these concerns.

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Pipeline Transportation Systems

The February edition of **Beaufort** Magazine was dedicated largely to describing tanker transportation systems that can be used to take Beaufort Sea oil to southern Canadian markets. In this edition we examine the pipeline systems that will be used to transfer oil between production islands, to shore bases and possibly overland to southern destinations. Pipelines are the most proven and cost effective means of transporting oil and natural gas overland, particularly for long distances. A network of subsea pipelines will be required to join the production islands in the Beaufort Sea to each other and to an offshore tanker loading dock, or to a shorebased facility.

The reason that **Beaufort** Magazine has devoted entire issues to tankers and pipelines is that the major proponents advocating Beaufort Sea oil development recognize that both transportation systems are feasible to deliver that oil to market. Furthermore, the proponents firmly believe that the environmental and socio-economic impacts of both systems can be maintained within acceptable limits.

Pipelines are often built in conjunction with oil field expansion programs. A recent example of this is provided by the forthcoming expansion of the Norman Wells, Northwest Territories, oil field by one of the Beaufort Sea proponents, Esso Resources Canada Limited. Government approvals were received in 1981 to expand the present field from a 3,000 barrel a day rate up to 27,000 barrels, and to build a 30 centimetre (12 inch) pipeline from the Norman Wells field to Zama Lake, in Alberta. The buried pipeline which will be built and operated by Interprovincial Pipeline (NW) Ltd., will have three pumping stations, and be capable of transporting more than 25,000 barrels daily by mid-1985.

In this edition of **Beaufort** we examine some early history of pipelining in Canada, the current



network and contribution of pipelines across Canada, the technology of subsea and overland pipelines in the Arctic environment, and the successful application of that technology as exemplified in the Alyeska Pipeline. As in previous editions we have written a profile on an important Arctic mammal - this edition will tell our readers about the caribou, our deer of the north.

Environmental Impact Statement (EIS)

As explained in earlier editions of this magazine, before government clearances for development and production of Beaufort Sea oil and gas can be obtained, the proponents of development must submit a comprehensive report on the possible effects and impacts of their projected activities. The report, or Environmental Impact Statement (EIS), is scheduled for completion this summer and will be submitted at

that time for review by the Beaufort Sea Environmental Assessment Panel, appointed by the Minister of the Environment.

A series of hearings were held during the latter part of 1981 by the Environmental Assessment Panel to help clarify and establish the guidelines for the preparation of the Environmental Impact Statement. As the result of those hearings the final guidelines were released in February, 1982. These guidelines are assisting the proponents in preparing the Environmental Impact Statement which will subsequently be available for review and evaluation by all interested parties.

The EIS will consist of 7 main volumes and is being written for both lay and specialist readers. Based on the present schedule, the EIS should be completed by the summer of 1982. Thereafter, the documentation will be subject to review, followed by the main series of public hearings.

CANOL PIPELINE

A History of the Norman Wells to Whitehorse Oil Pipeline

Welded pipe running northward along railroad 1 mile out of Carcross. (Photo courtesy Bechtel Group Inc.).



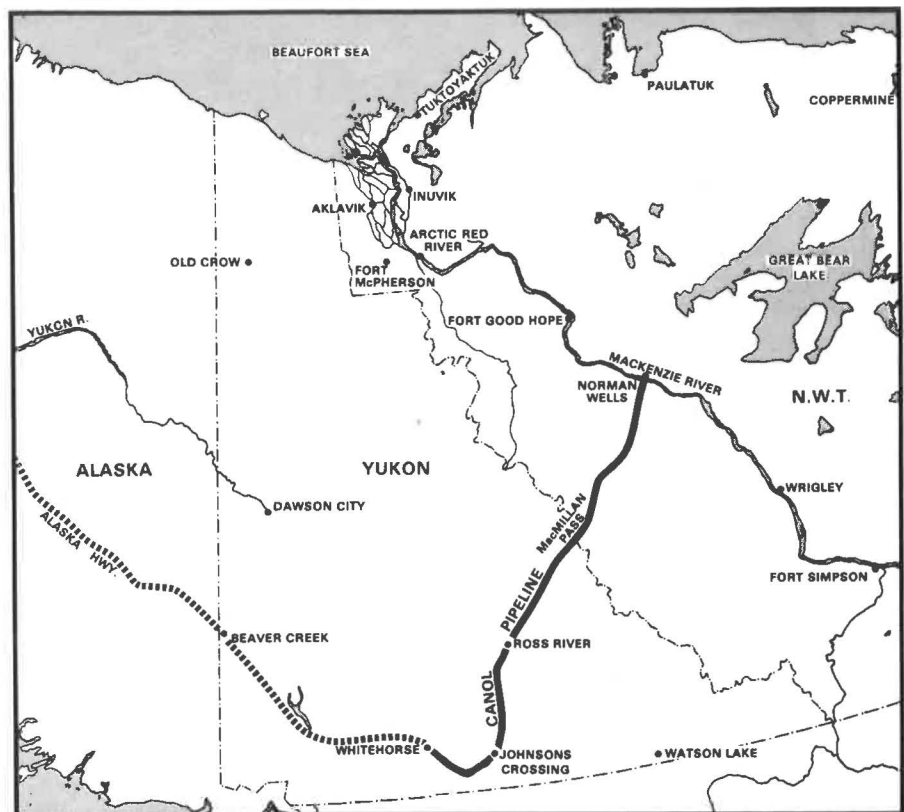


Troops stacking pipes! (Photo courtesy Bechtel Group, Inc.).

The first major oil pipeline built in the Canadian Arctic no longer exists and, because of wartime secrecy surrounding its construction, the Canol pipeline story has become an obscure, little told chapter in the history of Canadian energy development. The story begins in 1942, a sombre time during the Second World War, when the United States was struggling to build a defensive capability in Alaska against a possible Japanese invasion.

Construction of the Alaska Highway was commenced to provide a land link which would parallel a string of airfields starting at Edmonton, Alberta. The airfields were refuelling stops for aircraft being ferried to Russia under the Lend-Lease scheme. They also provided a vital link between the mainland United States and the defending forces located in the far flung Aleutian Islands who relied on those airfields and the Alaska Highway for re-supply.

America was worried about the loss of oil tankers through enemy



The Canol pipeline, as shown here was built to connect the Norman Wells oilfield (NWT) with a new refinery in Whitehorse (Yukon Territory).



Northwest Territories 1942: To save time, the pipeliners often lunched on the job instead of going back to camp, and they thought of the sign in the employment offices: "This is no picnic....". (Photo courtesy Bechtel Group, Inc.).

submarine attacks along the west coast, and therefore wanted a more secure land based source of oil close to the Alaska Highway route. They particularly needed aviation gasoline for the aircraft flying to the Aleutians and Russia. Various sources were discussed, including oil fields in Alberta or Southern Alaska, but the Norman Wells field in the Northwest Territories was finally selected.

The famous Arctic explorer, Vilhjalmur Stefansson, had spent many years in the Mackenzie River delta and cautioned the United States War Department that a solution would have to be found for building on top of permafrost - a caution which seemed to be largely unheeded, at least at the outset. The technology of building roads and pipelines in the Arctic was not well developed in 1941 when the Canol line was proposed.

In an amazingly brief period of

time the United States launched a massive construction program in the Canadian Arctic to develop further the Norman Wells oil field and to build a pipeline from the Wells to a proposed refinery at Whitehorse, Yukon. Under a cloak of wartime secrecy, the Canadian government authorized the project to go ahead in May, 1942.

By summer the first of some 225,000 tons of construction supplies and 2,560 kilometres (1,600 miles) of 10 centimetre (4 inch) pipeline arrived at Waterways, Alberta near Ft. McMurray for the arduous barge journey to Canol Camp, on the west bank of the Mackenzie River, opposite Norman Wells.

The backbreaking construction and stevedoring work was accomplished by troops of the U.S. Army's Engineering Corp through the winter of 1942. The road to parallel the pipeline, started in January,

1943, rivalled the Alaska highway in difficulty as it followed an old Indian trail through the unexplored Mackenzie Mountains.

A consortium of three civil construction firms (W. A. Bechtel Company of California, H. C. Price Company of Oklahoma, and W. E. Callaghan Construction of Texas) plus Standard Oil of California were responsible for the building and operation of the pipeline and oil refinery at Whitehorse. Bechtel-Price-Callaghan, as it was called, hired more than 52,000 civilian workers to build the pipeline. Despite strong warnings about the rugged working conditions, and despite the excellent pay, less than half of those workers would complete the nine month contract period. The severity of the Arctic climate and the work discouraged all but the strongest.

The great sense of urgency fostered in the wartime environment meant that the pipeline did not have to meet commercial standards. The Canol builders knew the pipeline was not commercially viable. It has been estimated that about \$300 million dollars was expended on the program. In the haste to complete the line it was simply laid along side the road, often without supports or reinforcements. It was vulnerable to frost heaving, snowstorms, flooding and any other hazards because it was exposed to the elements. Few of the precautions commonly employed in later years by pipeline construction companies were used to complete the Canol line.

The pipeline was completed in February, 1944 and transported its first barrels of oil to Whitehorse in April of that year. Up to March, 1945 the Whitehorse refinery processed about 984,000 barrels of oil from the Norman Wells field. Due to mechanical difficulties only a miniscule 20,000 barrels of aviation gasoline came from the refinery, at an enormous cost of over \$43 a barrel, the balance being diesel and vehicle gasoline.

The environmental impact of Canol related mainly to the building of the road that paralleled the

pipeline. The builders learned the hard way that removing the low-lying vegetation above the permafrost exposed it to radiant heating, causing the ground to thaw and turn into a quagmire. Many vehicles sank into this mire before the construction company learned that the way to prevent thawing was to insulate the ground with gravel or branches. They also learned that plowing down shrubs and trees caused severe erosion, and coupled with permafrost melting, turned many of the access roads into muddy ditches. The knowledge gained in building the Canol road was applied to later projects in permafrost regions.

Apparently much of the pipe used for the Canol line was not designed for extremely cold temperatures and was not handled properly during construction. It broke frequently during operations and thousands of barrels of oil were spilled during the line's brief operating history. Surprisingly, environmental damage caused by the Canol project seems to have been minimal or transient. R. Alex Hemstock, director of environmental studies for Canadian Arctic Gas Study Ltd. and a former engineer on the Canol project, was quoted in the November 1977 issue of Audubon magazine as saying, "We've looked at Canol. We went back and examined it. There was no evidence of harmful effects. The hunting and fishing access has increased, and there might be some impact on wildlife. But this would have happened anyway, even without the road. With regard to the oil spills, the scale of the river is so immense they would have been insignificant. The Mackenzie has a heavy sediment load. Most of the oil emulsified and disappeared within a short period of time." 1

Today the Canol Road is a hiker's trail. The bridges built to ford the many rivers between Norman Wells and Whitehorse have been washed away by spring floods. However,

1. Philip L. Fradkin, *The first and forgotten pipeline*, Audubon, November 1977, page 77.



Welding between Mile 94 and Mile 95 north from Skagway. (Photo courtesy Bechtel Group, Inc.).

the section between Whitehorse and Ross River is still in use. The pipe itself was dismantled after the war ended, and the refinery at Whitehorse was shipped to Edmonton, Alberta, becoming the city's first following the Leduc oilfield strike!

Imperial Oil had drilled over 60 wells in the Norman Wells field to support the Canol pipeline, and there had been some optimistic forecasts that after the war this field would become an important source of energy for North America. However, in that era of low energy prices there were more accessible oil fields from which to draw.

The need for Canol pipeline was rapidly overtaken by events during the war and, in retrospect, it probably should not have been built. Others have argued that Canol was a good example of how

not to build a pipeline although, in truth, laying the pipeline along the frozen ground without proper protection and reinforcement bears no resemblance to modern pipelaying techniques. The lessons learned related mostly to road construction in permafrost terrain, rather than the technology of pipelaying itself.

The early mistakes made in building over permafrost were not repeated in later, successful pipelines such as the trans Alaska which was built over similar terrain to that of Canol. In fact, the contrast between those two lines is vivid proof that the lessons have been well applied in the intervening years, and that technological solutions can successfully protect and accommodate Arctic permafrost.



The width of the pipeline right-of-way is much broader than the pipeline trench in order to accommodate construction equipment and working area. (Photo courtesy TransCanada Pipelines).

Pipelines Across Canada



The welded sections of pipeline are bent to match the land contours, and are placed in the trench by side-boom tractors. (Photo courtesy TransCanada Pipelines).

There are more than 160,000 kilometres (100,000 miles) of pipeline, transporting natural gas, oil and other hydrocarbons in Canada. Pipelines are the most economical and safe means of energy transfer over the land, and with the least environmental impact. The greatest percentage of these lines are buried underground, unseen, unheard, and making no intrusions on our daily living other than to provide the energy we need.

Pipelines in the form we see today are a recent invention, constructed mainly since the Second World War. The first all-Canadian oil pipeline was built in the 1920's between Turner Valley and Calgary, Alberta; but the first major line was Interprovincial Pipe Line Ltd.'s from Edmonton, Alberta down to Superior, Wisconsin in 1950, a distance of 1,820 kilometres (1,130 miles). The Trans Mountain



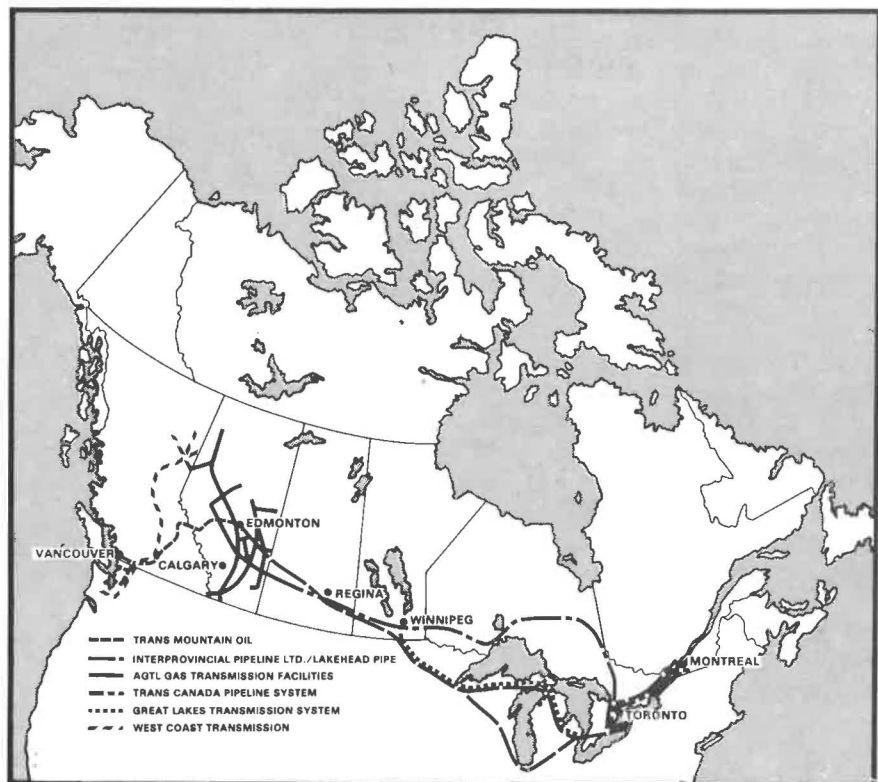
Pipelines can vary in diameter dependent upon the size of gas or oilfield, and the rate of daily flow from the field. (Photo courtesy TransCanada Pipelines).

pipeline, 1,250 kilometres (780 miles) long, stretches from Edmonton to Vancouver, B.C. and Seattle, Washington, and was built in 1953.

Since then, TransCanada Pipelines has built a 9,300 kilometre (5,800 miles) system from the Alberta/Saskatchewan border to Montreal, Quebec while Nova, an Alberta Corporation, (formerly Alberta Gas Trunk Line Company Limited) today operates a 9,600 kilometre (6,000 miles) natural gas network that handles the largest volume of gas in North America.

In the early days pipe was made from cast iron and was joined using lead sealant, or was threaded to form a screw-in joint, but today's pipelines are made of high quality steel, meeting stringent specifications. It is welded together, and after being cleaned, primed, coated and wrapped to prevent corrosion, it is lowered into the ground, usually with a minimum cover of about 0.9 metres (3 feet).

The strip of land that the pipeline

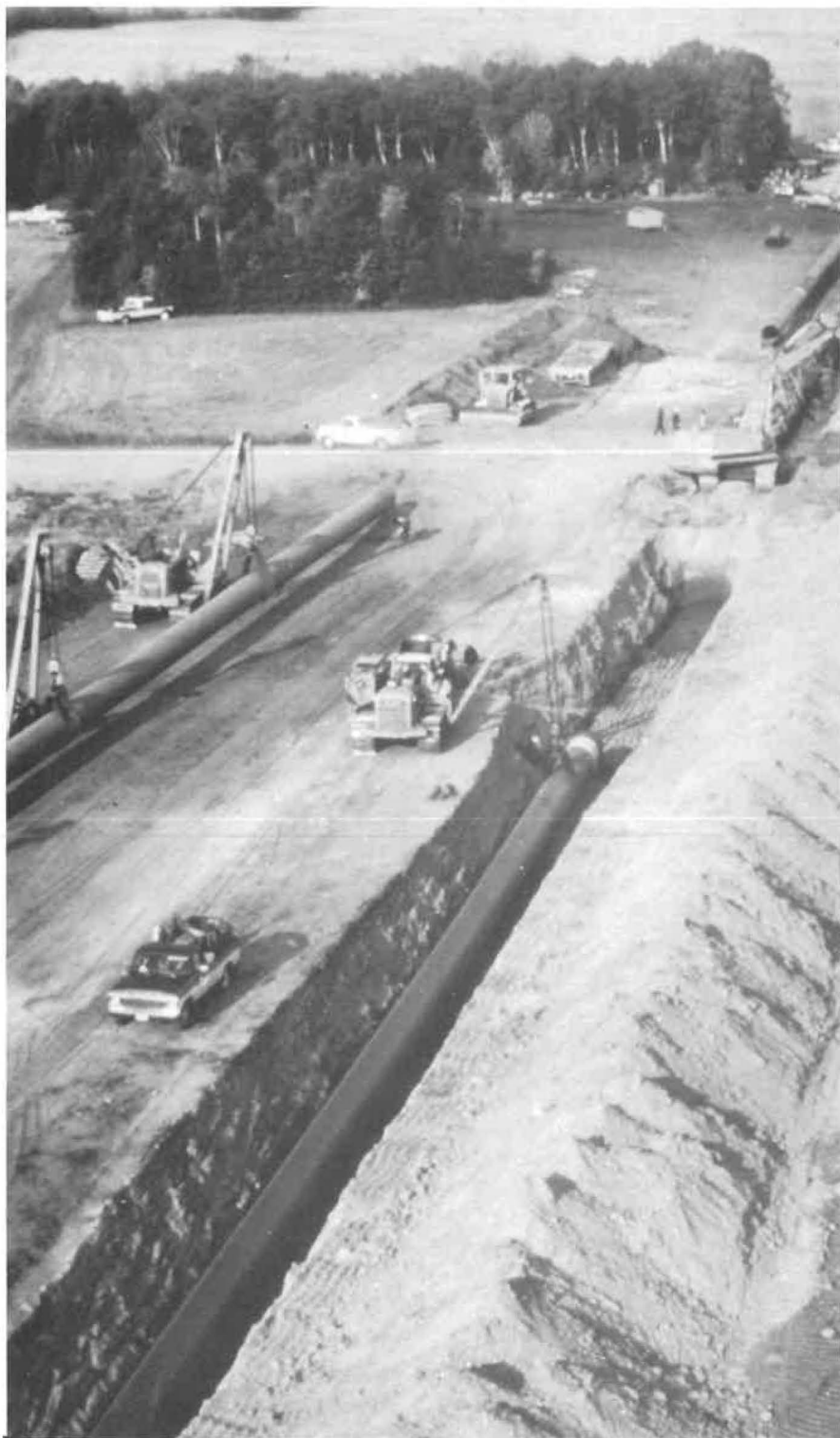


This map of Canada shows the routing of the major gas and oil pipelines between Vancouver and Montreal, and which companies operate and service them.

ditch is cut through is called the right-of-way, and is typically cut to a width of about 18 metres (60 feet). After the pipe is laid in place, it is covered with soil and reseeded. Farmland is returned to cultivation. The system is pressure tested, usually with water to higher than normal operating pressures, to ensure that the in-place pipe will meet the design requirements prior to carrying any oil or gas.

The distance between pumping stations can vary - in a mountainous district stations may be less than 100 kilometres (60 miles) apart, while on flat land they may be separated by as much as 200 kilometres (125 miles) in the case of oil, or 100 to 110 kilometres (60 to 70 miles) for natural gas. Most pipelines today are computer controlled from an operations control centre and are monitored continuously in the remote event of a leak. Telemetry systems can detect a pressure drop along the line, and valves can be closed either manually or automatically to isolate a suspect section of the line. Pipeline right-of-ways are customarily flown over weekly or monthly to ensure that no leakage is evident - a leak will be detected by discolouration of the vegetation. Although corrosion and weld flaws occasionally result in pipeline leaks, the most common cause is human disruption when farm or construction machinery digs too deeply along a right-of-way.

Oil travels through the line at speeds up to 10 kilometres per hour (6 mph) with the aid of pump stations, whereas natural gas can travel at speeds up to 32 kilometres per hour (20 mph) using compressor stations to squeeze the gas and accelerate it through the line. Oil pipelines are cleaned internally on a regular basis using a device called a "pig". It has spring mounted scraper blades and brushes which remove the paraffin and dirt build-up that accumulates on the walls of the piping. The "pig" travels in the oil and the dirt removed dissolves in the oil, or is caught in



After the pipeline is laid, as in this photo, it is covered by a minimum of one metre of soil cover, and the right-of-way is re-seeded and restored to the original condition.

traps at pump stations along the line.

Research continues on pipeline technology, particularly as it relates to transporting oil and gas from the

frontier regions. Because they are such a cost-effective and well proven transport method, pipelines will always be an integral part of our future energy system.



Caribou breed during a brief rutting season in the fall, and do not mate for life. The antlers of the male usually drop off after the rutting season, and regrow in the spring and summer. (Photo by George Calef/Courtesy of the Northwest Territorial Wildlife Service).

CARIBOU

The Deer of the North

The caribou, one of the more primitive members of the deer family, is widely distributed throughout the Canadian Arctic. There are herds on Baffin Island in the eastern Arctic, along the west coast of Hudson Bay, through the interior and coastal regions of the Northwest Territories, and westward to the Yukon/Alaska border. There are numerous sub-species through these regions, although the most abundant is called the barren-ground caribou (*Rangifer tarandus groenlandicus*). The Bluenose herd migrates in the region east of the Mackenzie River Delta and the Beaufort Sea, and the well known Porcupine herd, made up of a sub-species called Grant's caribou, migrates between Alaska,

the Yukon and the Northwest Territories border.

An important sub-species called the woodland caribou (*Rangifer tarandus caribou*) has similar traits to the barren-ground caribou and is found on the east and west sides of the Mackenzie River, particularly between Norman Wells and Ft. Simpson. In the summer months the Woodland species seeks alpine tundra in the Mackenzie Mountains to the west, and in the winter migrates to the open black spruce-lichen forest along the Mackenzie Valley. Compared to the barren ground species, the Woodland caribou is more solitary and does not gather in large concentrations. Migrations appear to be relatively short range, and they seek open

tundra in mountainous terrain for calving, such as in the McConnell Range of the Franklin Mountains.

There is a domestic version of the caribou, called the reindeer (*Rangifer tarandus tarandus*), which is herded in the Mackenzie Reindeer Grazing Reserve. They were originally brought to the Delta from Alaska to provide residents with a reliable food supplement. The herd is owned by Canadian Reindeer (1978) Ltd., and is operated out of Tuktoyaktuk by William Nasogaluak. The herd numbers approximately 12,000 and winters in the area west of Eskimo Lakes, calving in April around Parsons Lake and spending the summer on the northern part of Tuktoyaktuk peninsula.



Leadership in caribou herds can change, and often females lead the herds during spring migration to the calving grounds. The barren-ground caribou migrates regularly and changes feeding grounds several times a year. (Photo by George Calef/Courtesy of the Northwest Territorial Wildlife Service).

Caribou are well adapted to the Arctic climate. They shed their winter coats in the spring and early summer, growing a dark brown, short haired coat marked with white fur along the flanks, belly, and near the hooves. In late fall and winter white-tipped guard hairs cover the summer coat. The winter coat is quite warm because the hairs are hollow, with the air cells preserving body heat by insulation. This also helps the caribou float high in the water, and contributes to an excellent swimming ability.

The caribou's hooves are large and sharp edged, providing good support over muskeg and snow. During winter the pads of the hoof shrink and become hard, and hair grows between the toes in thick tufts, protecting the pads against the frozen ground.

Caribou live on a diet of lichens, dried horsetails, and sedges, as well as the leaves of evergreen shrubs during the winter months, replacing this with flowers, mushrooms, grasses, berries and the leaves of willow and dwarf birch in summer. They chew their own antlers after they fall off, apparently as a mineral supplement.

Barren-ground caribou bucks weigh about 110 kilograms (240 pounds) and measure about 110 centimetres (43 inches) at the shoulder. Both males and females grow a set of antlers annually. The antlers are made of bone and, in males, start growing in March. Cows develop their antlers over the summer months and their calves start growing their first set when three months old, shedding them in May or June of the following year. At first the antlers are flexible and covered in velvet which contains a network of blood vessels. Once their antlers harden in mid-September the bulls rub off the velvet against trees, exposing the large white horns which are used for display and combat during the short rutting season in October and November.

The gestation period for caribou generally averages 228 days, following the short breeding season. Does give birth to one calf weighing about 5 kilograms (11 pounds), following a brief labour in late May or early June. Gangly and awkward at birth, caribou calves develop very quickly and are capable of running with the herd within a day. They are usually weaned from mother's

milk within a couple of months. Barren-ground caribou do not mate with one animal for life, as they are polygamous, and there are no firm patterns of leadership in a herd. Sometimes leadership changes, with cows leading and bulls following, particularly during the spring migration. The only strong ties are between cows and their calves in the first year after birth.

Caribou herds are nomadic and do not spend lengthy periods of time in one place, but rather move from one seasonal pasture to another. Each year there are concentration periods when bands congregate into huge herds of up to 100,000 animals. This can occur in late winter prior to migration to summer pasture, after calving in the summer, and in early autumn prior to the rutting season.

The calving grounds may be as much as 700 kilometres (430 miles) from their winter quarters. Pregnant cows lead the spring migration, driven by the urge to reach these grounds before giving birth. The grounds appear to be chosen for their barrenness, often being rocky, exposed and windy. It has been speculated that cows choose such regions because few predators can live there, and it provides a dry, mosquito free shelter for the calves.

Caribou have a number of enemies, the most significant being wolves and men. In addition, depending upon location, they may fall prey to grizzly bears, lynx, and wolverines. Eagles will attack calves, as well as juvenile caribou or those weakened by age or a harsh season. Healthy adult caribou can usually outrun wolves, although the best protection for them is the herd. A group of animals is more likely to detect a predator and trigger a warning for the herd to run.

Calves which become separated from their mothers are unlikely to survive; this can occur when the herd is disturbed and stampedes. Mothers and calves recognize each other by smell, and cows will tolerate only their own offspring, kicking out or using their horns to ward off a strange calf that comes near. Wolves and hunters often



A caribou buck is illustrated standing next to a section of the trans Alaska pipeline. The caribou has adapted readily to the pipeline and Prudhoe Bay oilfield, and occasionally will migrate and feed in the industrial, populated sections of the line. (Photo courtesy Alyeska Pipeline Service Company).

ambush caribou during their congregations near water, and the herds are especially wary prior to swimming across a river or lake. They are often injured during river crossings, or drown because of swift currents, rapids and drifting ice.

Native hunters of the Arctic, who value caribou as a staple food, harvest many thousands every year for domestic use. It is estimated that wolves kill about 20 to 30 percent of the calves and approximately 5 percent of the adults in a given year. Caribou are almost constantly on the move, and particularly so during the summer months when they are harassed by insects. They seek windy knolls, cool snow patches, and shallow water as a relief from black flies and mosquitoes.

Caribou and Industrial Development

Much concern has been expressed about the possible impacts of industrial development in the Arctic on caribou herds, and considerable research continues to be carried out to learn more about the animal's reactions to roads, pipelines, and terminal facilities. Experiences at Prudhoe Bay, Alaska, and along the trans Alaska pipeline have shown that caribou behaviour varies around industrial sites. For example, during the summer season they have often been seen wandering close to buildings, oil wells, storage facilities and airports with no apparent regard or fear.

On other occasions caribou have been seen to be quite wary of

human activities, particularly cows with their calves, who steer well away from habitation, roads and pipelines. It appears that roads and vehicle traffic are seen as a potential source of danger by the cows. Human hunters travel the roadways and caribou have been victims of vehicle collisions. In certain years caribou have been seen to graze for weeks in the Prudhoe Bay area. For example, in 1973 a herd spent the summer there, despite a human population of several thousand.

Surveys conducted by the Yukon Department of Renewable Resources and the Canadian Wildlife Service on the Porcupine herd in the vicinity of the Dempster Highway have revealed an encouraging pattern of range use. Adverse reactions to the highway were observed in 1973, when hunting was permitted

from the road. Since the highway was closed to hunting in 1978, caribou have wintered near the road without obvious major negative reactions to the low level of vehicle traffic, about seven vehicles per day. This is an encouraging sign that caribou can adjust to man-made obstructions on the winter range, at least in the absence of hunting and a high level of vehicle traffic.

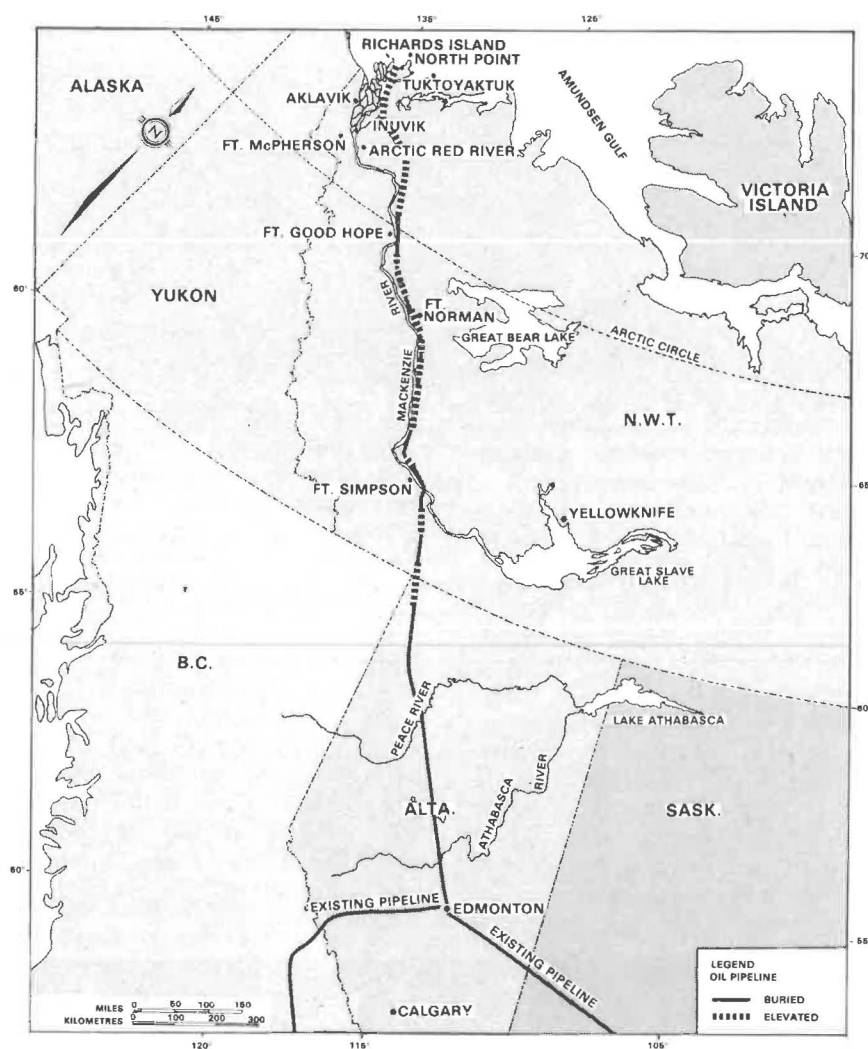
Based on studies completed to date caribou herds appear to have been relatively unaffected by the trans Alaska pipeline. The caribou herds have shown themselves to be quite variable in their migration routes, whether industrial activity was present or not. There is no evidence that their population density has suffered because of such activity and, in fact, wide fluctuations in population density have been observed and reported both in native folklore and by biologists in the field.

Recent experiences with pipeline construction and research on caribou behaviour suggest that it is often easy to accommodate to their needs. The caribou has proved to be a tough and resilient species. With adequate regulations and due consideration given to their needs, the activities of the oil industry should pose few, if any, threats to the survival of this magnificent species.



Caribou calves develop very quickly after birth. They can usually stand and run within hours, and move with the herd within the first day of birth. (Photo by George Calef/Courtesy of the Northwest Territorial Wildlife Service).

Overland Pipeline System from the Beaufort



This map illustrates the Beaufort Sea oil pipeline route that is proposed from Richards Island, travelling 2,220 kilometres south to Edmonton, Alberta. Elevated segments are indicated by the dotted lines.

An overland oil pipeline system from the Beaufort Sea coastline would probably originate from a tank farm at a proposed location called North Point on Richards Island. The line would proceed in a south southeasterly direction, passing east of Inuvik, the largest community in the Mackenzie Delta. Paralleling the Mackenzie River to the vicinity of Fort Simpson, it would then proceed south to a ter-

minal in northwestern Alberta. The final destination of the line would be the terminal of Trans Mountain Pipeline and Interprovincial Pipelines located on the east edge of Edmonton.

The total distance from North Point to Edmonton is 2,220 kilometres (1,390 miles). The pipeline size is naturally dependent upon the size of the oil reservoirs and would vary accordingly -

presents forecasts suggest a line between 24" and 42". Of the total length, approximately one third would be above ground, most of that segment being in the north where permafrost conditions require it. The elevated sections will be insulated, have an outer jacket of galvanized steel, and will be mounted well above the ground by vertical support members, spaced at appropriate intervals so that the pipe would not be damaged should a single vertical support member fail.

Using the well proven technology employed on the Alyeska Pipeline, the Beaufort Sea oil production pipeline would have "cryoanchors" within the vertical support members. The cryoanchors are remarkably simple in operation - metal tubes filled with refrigerant that draw heat out of the ground, whenever the ground temperature is warmer than the surrounding air. The cold air condenses, the refrigerant vapour to a liquid; the liquid sinks to the bottom of the tube which is submerged in the ground. The liquid absorbs the ground heat, evaporates, and rises to the top. The process repeats itself automatically, thereby keeping the permafrost frozen, and the pipeline stable.

Due to the wide range of temperature that the pipeline will experience, from frigid Arctic to temperate summer extremes, it must be able to expand and contract. This is allowed by securing the elevated pipeline in a "saddle and slide" assembly which can move both laterally and longitudinally. The pipeline will have anchors positioned at frequent intervals to limit the movement.

The buried section of the line, approximately two thirds of the total length, will use conventional buried construction methods with a minimum of one metre (3.2 feet) of

ground covering. Where the piping must pass through wet ground, due to a high water table, it will have weights attached, or a covering of concrete to keep it in place. The pipe will have a protective coating against corrosion, and in some sections strips of metal, serving as "sacrificial anodes" will be laid in parallel with the pipe to protect the line from electrolytic corrosion, caused by electric currents between the pipe and the soil.

Roughly 8 million cubic metres of gravel will be required for the construction of the pipeline, and the pumping stations. The pipeline right-of-way will involve a corridor of land up to 37 metres (120 feet) wide, to accommodate trenching equipment and backfilling. The right-of-way would be re-seeded and restored following burial of the line.

The Beaufort Sea production pipeline, if constructed on the east-side, will have six major river crossings; the Mackenzie River in the Delta and further south near Fort Simpson, the Great Bear River, the Peace River, the Athabasca and the North Saskatchewan. It will be buried deep enough in the beds of such rivers to avoid scouring by ice and/or water currents.

Pumping stations will be built along the pipeline; eventually there could be 24 such stations helping transport oil at a daily rate of 1.4 million barrels (218,000 cubic metres). Stations in the north will be specially designed for the Arctic weather and permafrost ground conditions. They will be built on gravel pads and, where necessary, refrigerated foundations will be used to keep the permafrost stable. The buildings at the stations will be insulated and interconnected with covered, heated walkways.

As with the Alyeska Pipeline, the first pump station would require some oil storage. The storage tanks will rest within a dike system that will have impermeable flexible liners designed for the extreme Arctic temperatures. In the remote event of a leak the dikes are capable of containing all the oil inside the storage tanks.

Seven of the northern pump stations will have systems which will be used to cool the oil from 27 degrees Centigrade to 21 degrees Centigrade, thereby reducing thermal stresses in the pipeline. Most of the pumping stations will have their own small topping plant, to refine the oil, and provide fuel to drive the turbine engines and related equipment at the station.

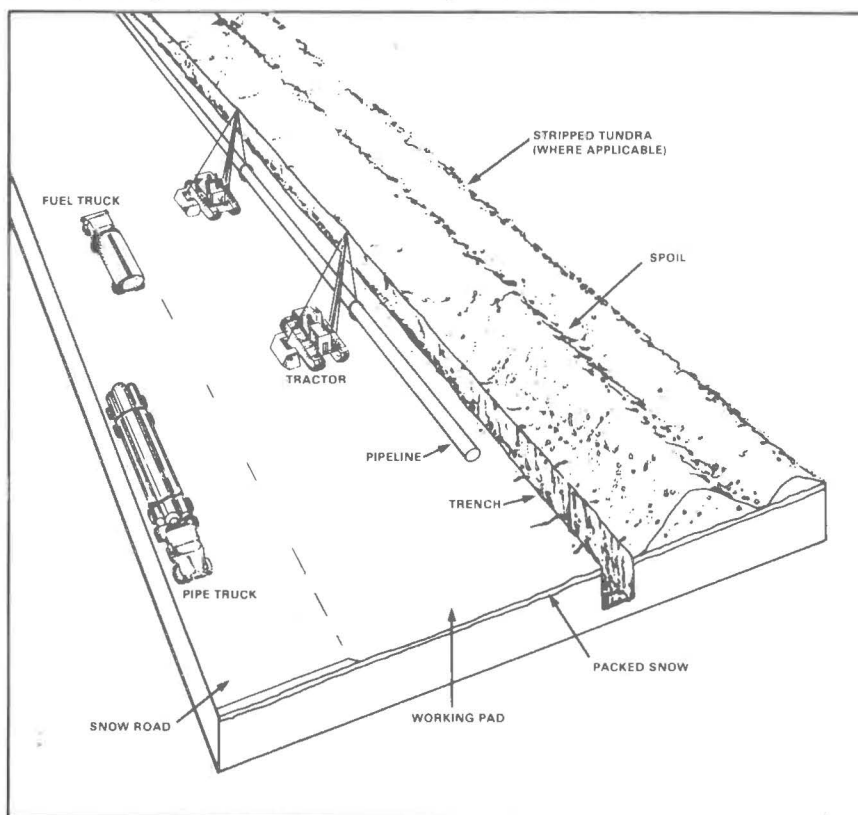
There will be a master control centre in Edmonton, Alberta from which all pumping stations can be operated. Maintenance, safety and inspection personnel can be housed at the stations to look after the electrical generators, heating plant, water treatment facility and sewage and waste disposal systems. All stations will have fire detection and automatic fire extinguishing equipment.

The building of the Beaufort Sea production pipeline will be a major undertaking. The closest similar project to it is the Alyeska Pipeline which has a diameter of 1.22

metres (48 inches) but is considerably shorter, being only 1,280 kilometres (800 miles) long. It is forecast that the pipeline will take about four years to construct, with the majority of activity taking place during the winter season when the terrain is frozen. Summer construction would include the building of the north and south terminals, the pump stations, and completing the major river crossings.

During the first two winter seasons major efforts would be expended on establishing the temporary facilities required to support the project - such as wharves, camp sites, access roads and airstrips. Material, fuel and machinery would be stockpiled using the existing waterways such as the Mackenzie and roads such as the Dempster and Mackenzie Highways. North of the 60th parallel personnel and camp supplies would be flown in by aircraft. A total of 17 temporary airstrips may be completed along the route to support the construction,

Buried pipeline in permafrost regions will be built using snow roads for temporary access, and snow work pads to minimize disturbance of the natural terrain.



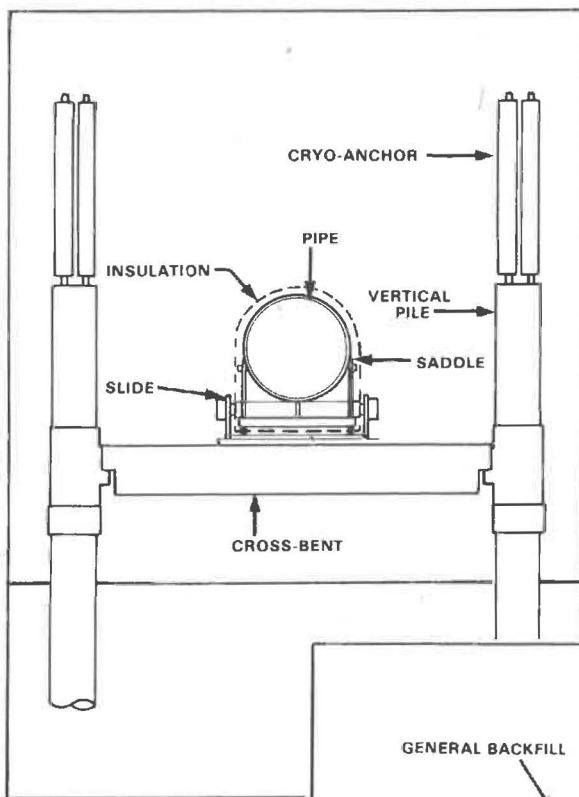
and later operation and maintenance of the pipeline.

At the peak of construction activities, during the winter of the third year, more than 13,000 people would be employed. Following the completion of the line about 200 permanent employees will be required to operate and maintain the Northwest Territories portion of the pipeline. This would increase to about 300 people by the year 2000.

In operation, the pipeline would be monitored 24 hours a day by pipeline dispatchers who can control the flow rate, start-up and shut-down, individual pumps along the route, and monitor valves and pressures. A leak detection system is planned which will signal if a leak representing roughly 0.5 percent or more of the oil flow occurs. The dispatcher will have a display panel signalling where in the system such a leak has occurred, and will be able to isolate the leak before a significant amount of oil has escaped.

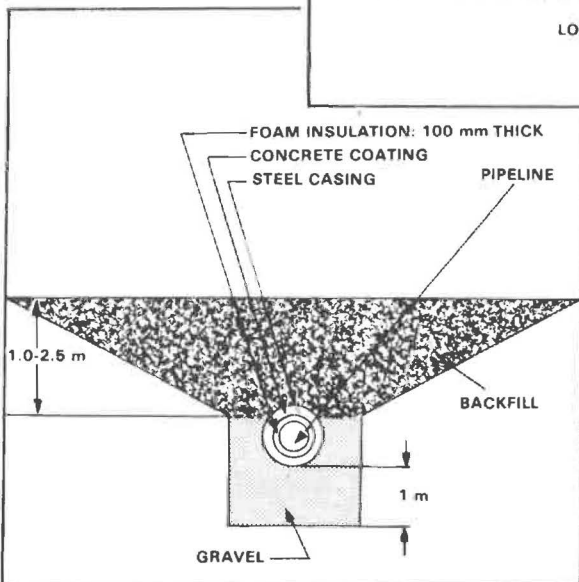
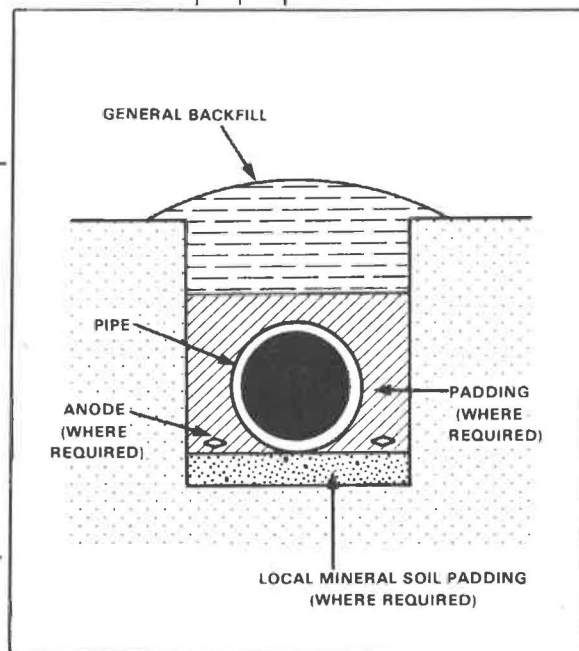
As with all pipelines, continuous surveillance and maintenance will help detect any potential problems, and protect the environment against damage. Both aerial and ground patrols will be used to identify any undesirable subsidence or erosion of the ground along the right-of-way. In sensitive permafrost terrain areas maintenance would, as much as possible, be conducted only during cold weather when the right-of-way is frozen.

The experience gained on other Arctic pipelines, particularly the Alyeska Pipeline, will be invaluable in building the Beaufort Sea oil pipeline. The environmental concerns expressed during the 1970s about pipelines through the Northwest Territories have been addressed, and real world experience has shown that there is minimal impact upon migrating animals and little damage to delicate ecosystems in the permafrost tundra of the North. The application of proven technology will ensure that energy needs and environmental protection can be incompatible objectives in building a pipeline in northern Canada.



This sketch illustrates how elevated pipeline in permafrost regions will look. The pipeline will expand and contract using moveable slides as support. The ground will be kept frozen by cryo-anchors with refrigerant inside, that will draw heat from the ground by evaporation.

This sketch illustrates the most common method of burying pipelines in the ground, using a relatively narrow, straight walled trench.



At river crossings the pipeline will likely have a foam insulating jacket, plus concrete and steel coatings. It will rest on a metre thick bed of gravel and have a substantial cover of local backfill.

The elevated sections of the Alyeska pipeline can expand and contract by virtue of sliding mounts that support the line. In permafrost regions, as illustrated here, the vertical support members are cryoanchors - the twin metal cylinders atop the support contain gaseous ammonia which by a process of continual condensation and evaporation draws heat from the frozen ground, thereby ensuring the stability of the ground and the pipeline. (Photo courtesy Alyeska Pipeline Service Company).

The Trans Alaska Pipeline Experience



In November, 1981 the trans Alaska pipeline attained a milestone when the two billionth barrel of crude oil reached Valdez, Alaska after an 800 mile journey from the Prudhoe Bay oil field. That barrel of oil took just under six days, travelling at about 5.75 miles per hour. From the Valdez terminal it was loaded onto a tanker bound for a refinery in the mainland United States. Oil transported through the trans Alaska pipeline provides about 10 percent of the United States' energy demands, with the Prudhoe Bay field accounting for 17 percent of all U.S. domestic crude oil production.

Prudhoe Bay is about 600 kilometres (375 miles) west of Tuktoyaktuk on the Beaufort Sea coastline, and has estimated

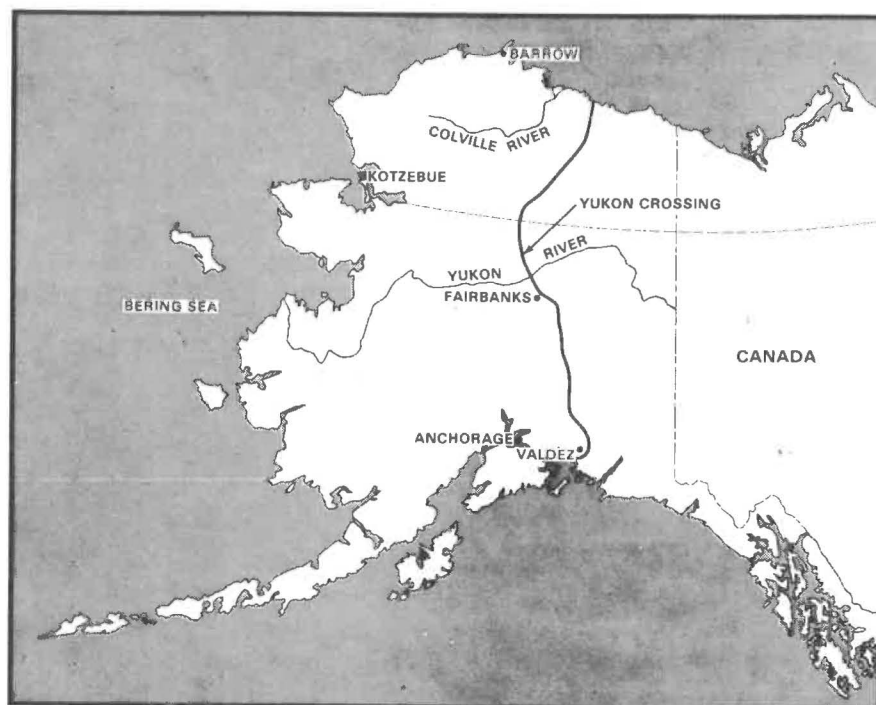
recoverable reserves of 9.6 billion barrels of crude oil and 26 trillion cubic feet of natural gas. Oil production from the field has now reached 1.6 million barrels a day, all of it transported via the trans Alaska pipeline. This line crosses three mountain ranges, hundreds of miles of permafrost tundra, and a total of 800 rivers and streams.

The 1.22 metre (48 inch) pipeline took just over three years to build at a cost of approximately eight billion dollars. About 672 kilometres (420 miles) of the pipeline's total length of 1280 kilometres (800 miles) are above ground on specially designed supports, 600 kilometres (376 miles) are underground, and 6.4 kilometres (4 miles) are both buried and refrigerated to protect the permafrost. The builder and operator of

the trans Alaska pipeline, Alyeska Pipeline Service Company, employed more than 21,000 people during the peak of construction in 1975 and pumped the first crude to an oil tanker in August, 1977.

Environmental groups had expressed grave concerns about the impacts of the trans Alaska pipeline prior to its construction, and there were several suits launched against the construction in 1970. However, after four years of operations it is becoming clear that the adverse predictions have simply not occurred, and the limited number of oil spills (only four of any significance) are proof of the integrity of the concept and the pipeline itself.

Disturbances to wildlife migratory patterns, population densities and livelihood have been virtually nil.



The route of the Alyeska Pipeline crosses Alaska north to south, some 1,280 kilometres from Prudhoe Bay on the Beaufort Sea to Valdez on the Pacific Ocean. 672 kilometres of the pipeline are elevated above the permafrost, and it fords over 800 rivers and streams.

There has been little damage to the permafrost layers along the pipeline route, and a re-seeding and re-vegetation program along the right-of-way has restored the narrow strip of land (only 12 sq. miles out of Alaska's total of 586,400 sq. miles) to match the surroundings.

The minimal impact of the trans Alaska pipeline can be attributed largely to the attention to detail that went into its construction. Half of the pipeline was raised above ground to avoid the possibility of melting the permafrost. But this exposed the elevated sections to wide temperature ranges from summer to winter, not to mention the contrast between the ambient air temperature and that of the oil. The pipeline has to handle a temperature range from minus to plus 50 degrees Centigrade.

To accommodate these extremes the pipeline is insulated with 10 centimetres (4 inches) of fiberglass and jacketed with galvanized steel. To allow it to expand and contract the line is mounted upon Teflon-coated shoes which can slide on the supporting crossbeams. The vertical

steel pipes which suspend the pipeline were anchored well below the thaw level of the permafrost, using ring shaped bulges around the circumference and a backfill of sand and water which when frozen forms an interlock between the support and the permafrost.

To guarantee that the ground would not thaw and cause heaving or displacement, certain sections of the pipeline are supported by thermally controlled vertical support members which use liquid and gaseous ammonia inside two hollow tubes. The tops of the tubes are exposed to the air - when that air is cold the ammonia vapour condenses to liquid and descends below ground to the bottom of the tube. The liquid absorbs heat from the permafrost layer, vapourizes, and ascends back to the top. This endless cycle draws heat from the ground ensuring that it remains frozen all year round.

At one highway crossing and two main caribou migration routes the trans Alaska pipeline is buried in a refrigerated ditch, with brine being circulated through loops of piping,

thereby maintaining soil stability. At other locations, the pipeline has been elevated high enough to allow caribou herds to pass underneath, although biologists have noted that the herds do not always use the special paths created for them, since they have no difficulty traversing the pipeline at most locations. Cows with calves appear to be more apprehensive about the pipeline, while bulls and yearlings seem unaffected.

Small streams and rivers were forded by burying the pipeline below the scour level in the riverbed. Large rivers were crossed using various types of suspension bridges. Key aquatic habitats of the main species of fish along the pipeline route, Arctic grayling, whitefish and salmon were considered when the line was laid. In one case a new salmon spawning channel was built to avoid some 4,000 feet of buried pipeline, and in a few cases adjustments have been made to certain stream beds to eliminate fish migration blockage.

The trans Alaska pipeline, in addition to having a minimal impact upon the environment, has proven to be an outstanding engineering success. During the early stages of operation the line carried about 750,000 barrels of oil daily, but over two and a half years the rate was progressively increased to approximately 1.6 million barrels presently flowing daily. This closely matches the optimum production rate of the Prudhoe Bay oil field, and the new nearby Kuparuk oilfield. The pipeline throughput could be increased to 2 million barrels daily with the addition of pumping capacity, should additional sources of oil be found in the North Slope region.

The pipeline has a total of 151 gate and check valves to control possible leaks. Eighty-seven valves protect stream crossings, 10 protect population centres, and 3 protect sensitive environmental sites. Check valves are designed to close automatically if oil flow stops or the oil flow is reversed, thus preventing a reverse flow of oil on uphill sections of the line if a leak occurs.

Gate valves isolate sections in downhill or flat terrain which may have a leak, minimizing spilled oil. Sixty-two of the 71 gate valves on the line can be operated from the control centre at Valdez. All valves can be operated manually for maintenance of the line.

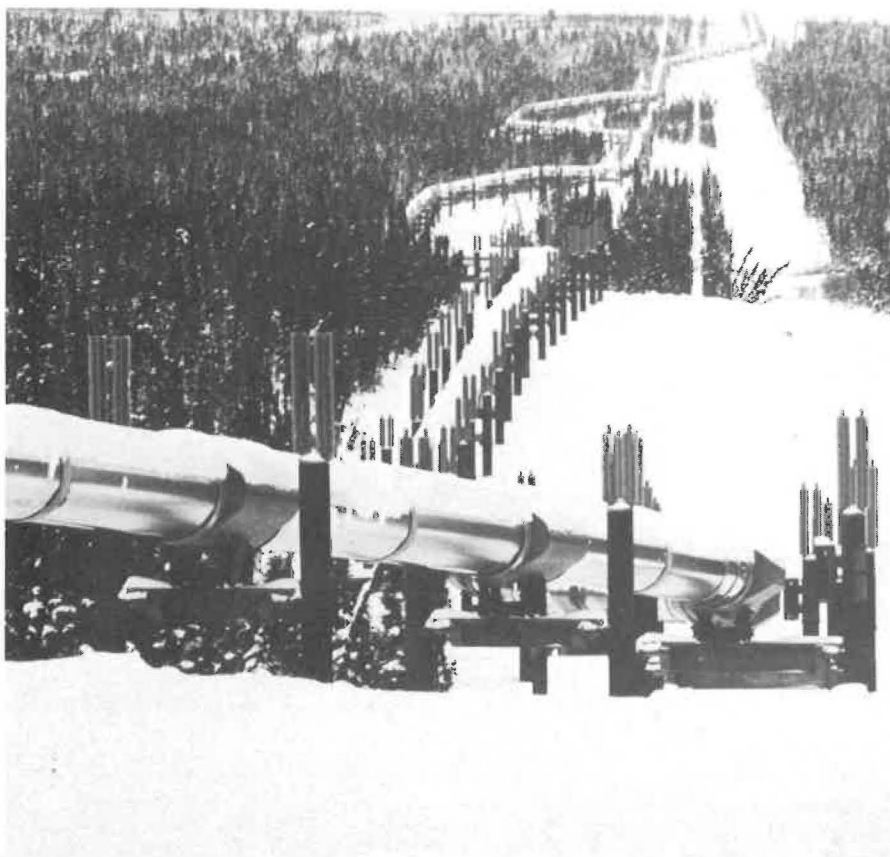
Buried sections of the pipeline can be subject to electrolytic corrosion, when a current flows from the pipeline to the soil. To prevent this the pipe is wrapped and coated, and strips of zinc ribbon are buried along with the pipe to serve as a so-called sacrificial anode - any current in the soil erodes the ribbon rather than the pipeline itself.

The Valdez terminal is situated at the northeast corner of Prince William Sound, the northernmost ice-free harbour in the United States. Valdez harbour can accommodate tankers of up to 265,000 dead-weight tons at loading rates of up to 110,000 barrels of oil an hour. The 18 storage tanks at the terminal can each hold 510,000 barrels of oil, or in total six days of pipeline throughput.

The Alyeska pipeline is a technological triumph which demonstrates clearly that the problems of construction over and through Arctic tundra can be accomplished while maintaining a high standard of protection for the environment. The early fears of irreparable damage have not occurred. Research and monitoring programs are continuing but it seems very unlikely that significant problems will be uncovered in the future.

(Top right): The Alyeska pipeline travels through terrain that is similar to that along the Mackenzie River valley. Much of the construction methods used are directly applicable to a Beaufort Sea oil pipeline.
(Photo courtesy Alyeska Pipeline Service Company).

(Right): The zig-zag pattern illustrated here is deliberately used on the pipeline to allow for the thermal expansion of the steel jacketed piping, caused by the large variation in temperatures from summer to winter, and the heat of the oil itself, which can reach 60 to 70 degrees Centigrade.
(Photo courtesy Alyeska Pipeline Service Company).



Subsea Pipelines for the Beaufort

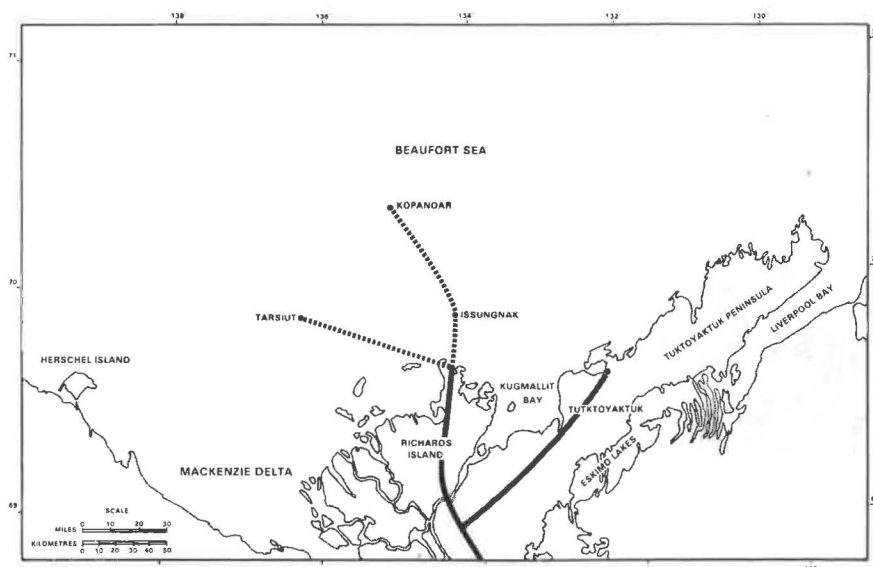
In earlier editions of the **Beaufort** Magazine we have described how artificial production islands would be constructed in the Beaufort Sea. As part of the production system, such islands would require a network of interlinked subsea pipelines. The currently projected pipeline scenario envisages trunklines for oil transmission from islands at Tarsiut, Kopanoar and Issungnak fields to shore, and inter-island flowlines for the transmission of gas, oil and water between the various offshore production islands. This network would be essentially the same whether oil is taken to market by tankers or an overland pipeline.

Subsea pipelines are a well proven concept, widely employed at other offshore production sites around the world, but there are special concerns which would be addressed in the Beaufort Sea. One of the major environmental design problems is that the ice keels of Arctic pack ice scrape and gouge the sea floor. This is a well documen-

ted phenomenon, one which is receiving additional research to determine both the degree and extent of ice scouring at various offshore locations and water depths.

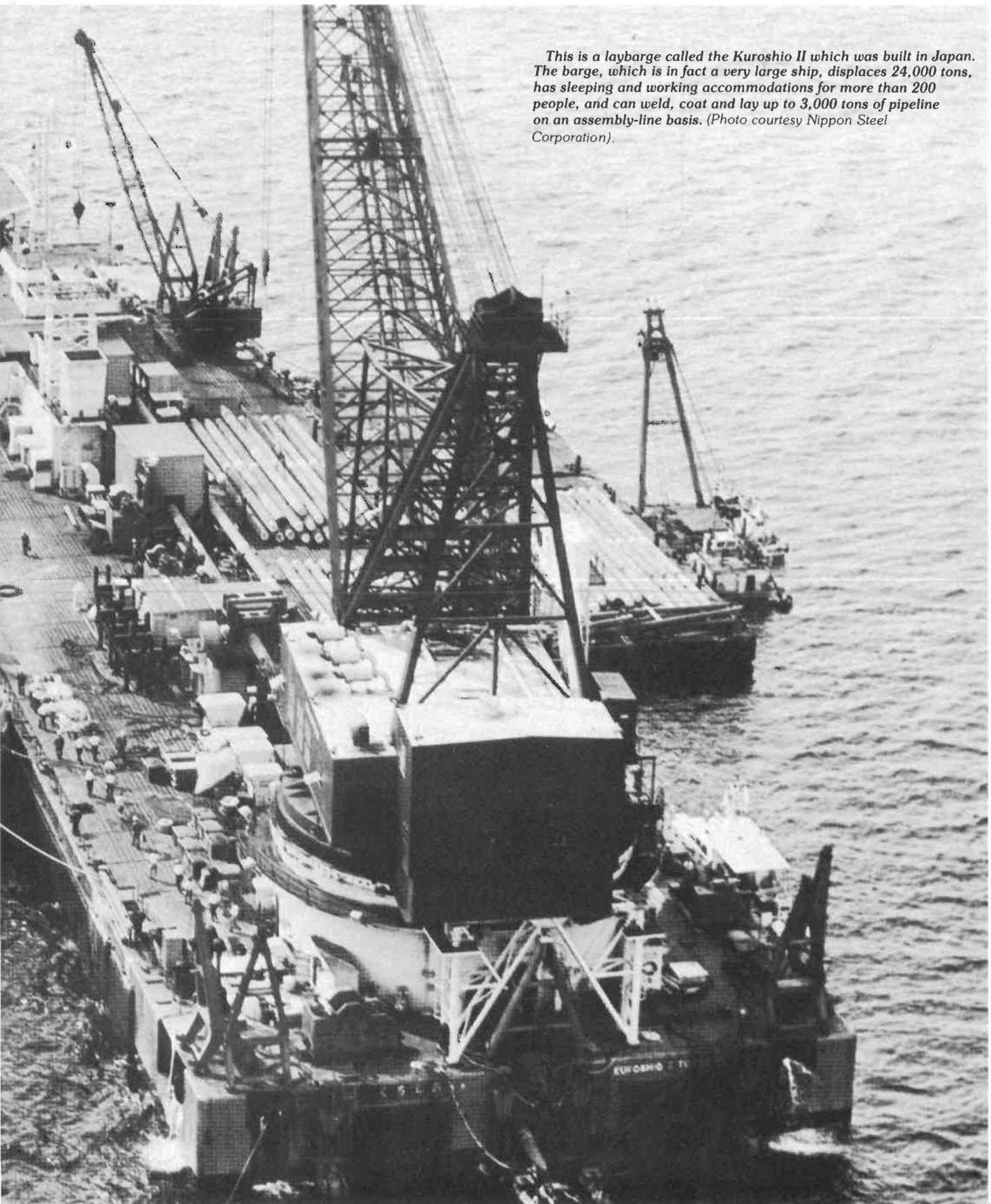
Research has revealed that the Beaufort seafloor is marked with frequent ice scours into water depths of about forty metres (131 feet). Beyond these depths few ice keels reach the bottom and we know that beyond 120 metres (393 feet) scouring is essentially non-existent. Some of the scour marks in deep water were produced thousands of years ago, when the sea was shallower, and for practical purposes scouring is not a problem for pipelines beyond 47 metres (154 feet).

Between the 2.5 to 15 metre (8.2 to 49.2 feet) water depth scouring is very common, but the depth of scours are shallow, being about 50 centimetres (20 inches) deep on average. In less than 2.5 metres (8.2 feet) of water, the sea ice becomes bottom-fast during winter



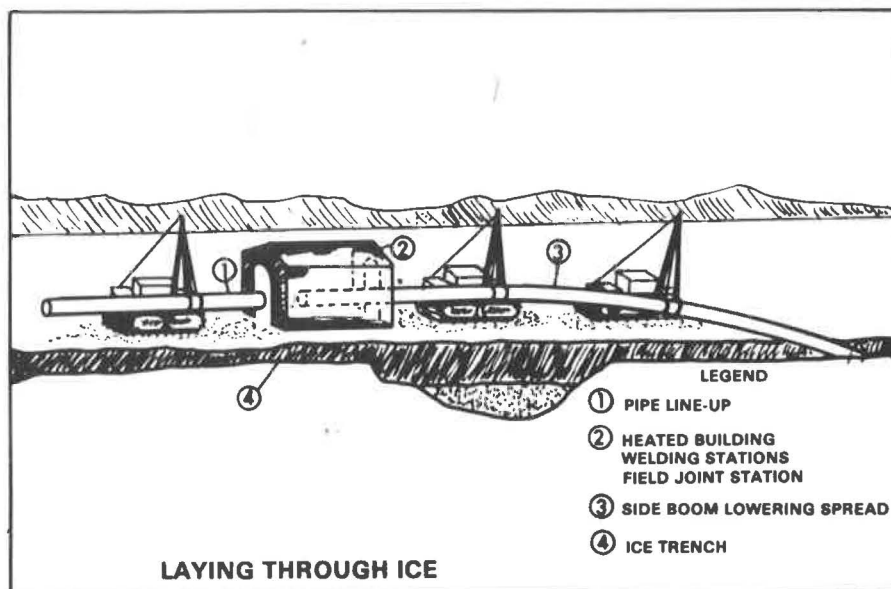
(Above): The three primary oil discoveries in the Beaufort Sea are illustrated here, showing the route of subsea pipelines to the proposed North Point terminal on Richards Island.





This is a laybarge called the Kuroshio II which was built in Japan. The barge, which is in fact a very large ship, displaces 24,000 tons, has sleeping and working accommodations for more than 200 people, and can weld, coat and lay up to 3,000 tons of pipeline on an assembly-line basis. (Photo courtesy Nippon Steel Corporation).

In landfast ice regions along the Beaufort Sea coastline conventional pipeline techniques will be adapted to allow pipe to be welded and laid directly through the ice, much as it would be done on land.



and deep scouring does not take place.

Based upon the available statistical information, and adding a substantial safety margin for unusually deep ice keels, experts forecast that in the area where the sea is 15 to 20 metres (49 to 65.5 feet) deep, subsea pipelines would be buried up to 4.5 metres (14.7 feet). In deeper water, for example around Kopanoar (60 metres/197 feet), the pipeline would be sunk into the bottom until the top of the line was flush with the seafloor.

Near the shoreline (from 2.5 metres (8.2 feet) above sea level to 2.5 metres below sea level) the pipeline must also be built with permafrost considerations in mind. To prevent melting of the permafrost, the subsea pipeline would be coated with a 10 centimetre (4.0 inch) insulation jacket and laid on a bed of sand or gravel.

The pipeline would not be buried as deeply in the shore zone, with the trench depth to the top of the pipe decreased from 3.5 metres (11.5 feet) nearshore to about 1.0 metre (3.1 feet) while coming onto land. To prevent ice from freezing to the pipe at the shoreline, and to protect the line from waves and currents, it would be backfilled with

coarse granular material.

Depending upon the type and source, oil leaving the well may be as warm as 66 degrees Centigrade. The natural cooling provided as it travels along the seafloor will decrease the oil temperature at the shoreline down to less than 13 degrees Centigrade. As previously mentioned, in sensitive permafrost regions the pipe will have an insulating jacket of foam and rest on a bed of gravel.

The diameter of the offshore pipelines will vary, dependent upon the daily flow rate of the field or fields being serviced. For example, a trunkline for the Kopanoar and Issungnak fields would be 76.2 centimetres (30 inches) in diameter and could transfer up to 95,000 cubic metres of oil a day, whereas the Tarsiut trunkline would be a 50.8 centimetre (20 inch) line to transport 20,000 cubic metres a day. As production rates increased at Kopanoar and Issungnak, a larger line or twin 76.2 centimetre (30 inch) parallel pipelines might be used.

The installation of the subsea pipelines in the Beaufort Sea will require detailed advance planning since most of the pipeline would have to be placed during the four month open water season. There are several state-of-the-art dredging and pipe-laying techniques which

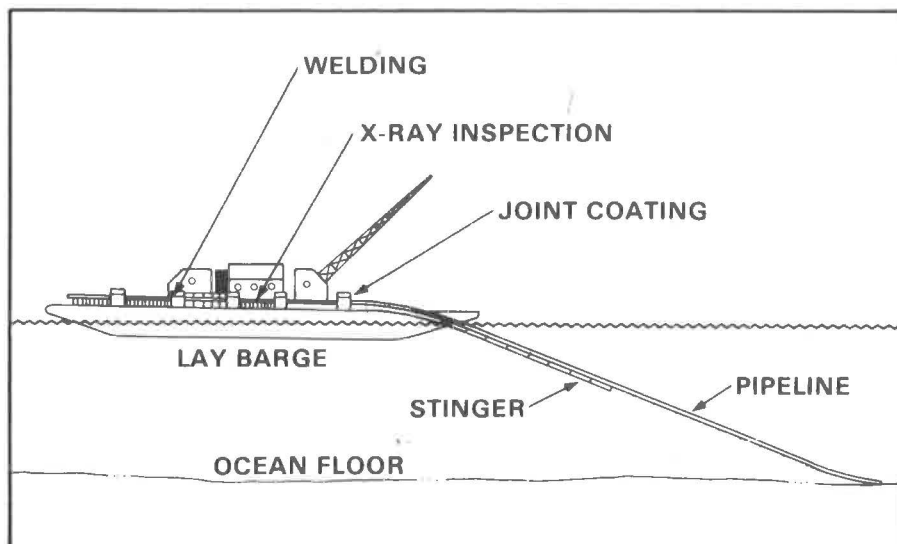
are applicable to Arctic waters, although a few specialized procedures would need to be developed.

Pipeline routes are being scrutinized in detail to a distance of 500 metres (1,640 feet) on each side, using side scanning sonar to generate comprehensive maps of the seafloor. The subsurface of that seafloor will need to be examined using borehole samples and low frequency acoustic scanners, thereby providing a thorough understanding of soil types and layering along the proposed right-of-ways. In addition, more data will have to be gathered on the surface winds, currents and wave patterns.

Dredges will be used to cut trenches up to 5 metres (16.4 feet) deep and 22 metres (72 feet) wide in the seafloor. It is estimated that the installation of the three major trunklines for the Kopanoar, Issungnak and Tarsiut oil fields would require the excavation of 7.8 million cubic metres of material from the seafloor.

One of the most widely used methods of subsea pipelaying employs a large and sophisticated ship called, somewhat misleadingly, a laybarge. A laybarge such as the Japanese Kuroshio II is 140 metres (459 feet) long and 34 metres (111.5 feet) wide, can store about

One of the techniques of pipelaying on the ocean floor, using a laybarge, is illustrated in this sketch. Welding, X-ray inspection and the coating of pipeline joints all takes place aboard the laybarge.



3,000 tons of pipe, hold up to 450,000 gallons of fuel for a 50 day operating period, has quarters for more than 200 working people, and displaces 24,000 tons! This is obviously not the standard image of a barge.

The pipe is loaded in segments aboard the barge and using an assembly line technique is automatically welded, using multiple welding stations. Following this the welds are checked both with X-rays and ultra-sonic testers. Then the welded seams are lined with plastic polyethylene and coated with concrete. The pipe sections have already been coated with plastic and concrete by the manufacturer. Large Diameter steel piping floats in water, and requires the additional weight of concrete to provide enough negative buoyancy to lower it to the seafloor. The concrete also provides the pipe with bottom stability, and protects it against mechanical damage.

Alternative methods of laying pipe can be employed, such as fabricating the pipe onshore in sections several hundred metres long. In the open water season a tugboat can tow the pipe offshore, or a barge with a high powered winch may pull the long 'strings' of pipe. This technique is likely to be used

for the smaller, gathering pipelines rather than the larger trunklines.

More than one technique may be used to lay the pipe in the shallow waters of the coastline. A shore-based winch may pull the pipe along as it comes off a laybarge anchored offshore. In quite shallow water where the ice is bottom-fast, land dredging techniques, and traditional pipelaying equipment modified for Arctic use will be used to put the pipeline in place.

Several techniques have been developed to lay pipe through the Arctic ice. One method involves drilling holes through the ice along the right-of-way, feeding through a wire guideline and then pushing the pipe through one hole and winching it into place using a sled located on the seafloor. This technique may be utilized in the landfast ice zone, but is not practical in the transition zone or regions where Arctic ice floes are constantly in motion, such as is common in the Beaufort Sea.

When the main pipelines to shore are in operation they will receive oil from the major oil fields through both trunk and gathering lines, and then transmit it to a shorebased terminal. At present it seems likely that the offshore network will cross the Beaufort Sea coastline at North Point on Richards Island. There is ample space there for a terminal,

pump station and airfield, and it is also close to a sheltered wharf at Hansen Harbour.

The safety record of subsea pipelines around the world has been excellent, particularly considering the thousands of kilometres that have been laid and the decades of time they have been operating. Leaks have generally been minor.

Pipeline repair techniques are well developed and there are a variety of methods available, in the remote event that a leak were to occur in the Beaufort Sea pipeline network. One method is to have divers descend in what is called a hyperbaric chamber to install a sleeve coupling around the break, or weld the pipe inside the chamber. Computer monitoring of oil flow rates will provide pipeline technicians with indications of a leak, following which the flow can be stopped by applying backsuction on the broken line.

The experience gained by the oil industry over the years in subsea pipelaying, and in overland pipelines such as the trans Alaska line, is readily applicable to the Beaufort Sea-Mackenzie Delta region. Methods for permafrost protection have been thoroughly researched and tested, and those methods have proved successful in the real world of the Arctic.

A barren-ground caribou calf born in the early Arctic summer. The caribou is a vital and essential animal to the Arctic ecosystem, and is one of the most widely distributed mammals through the Yukon, Northwest Territories and Arctic Islands. (Photo by George Calef/Courtesy of the Northwest Territorial Wildlife Service).

